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P.S.

GUIDELINES FOR THE GENERATION AND USE
OF
DATA IN MILITARY HANDBOOK 17A, PART I



JANUARY 1977

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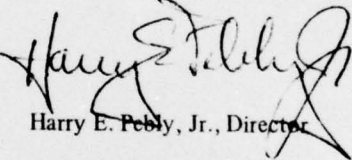
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by

JOSEPH A. MACIEJCZYK

ADOLPH E. SLOBODZINSKI

JANUARY 1977

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PLASTICS TECHNICAL EVALUATION CENTER
U. S. Army Armament Research and Development Command
Dover, New Jersey 07801

ABSTRACT

The procedures used for evaluating and characterizing fiberglass, boron, graphite and aramid reinforced composites are described as they apply to the 1971 revision of MIL-HDBK-17A, "Plastics for Aerospace Vehicles, Part I, Reinforced Plastics." The fabrication of test panels, the mechanical and physical properties considered, the test methods, the environmental conditions for testing and methods for presenting data are included.

FOREWORD

The current "guidelines" are to be considered as an addendum to MIL-HDBK-17A, *Plastics for Aerospace Vehicles, Part I, Reinforced Plastics*. This handbook is prepared and maintained by the Department of Defense as a standardization document. The Plastics Technical Evaluation Center, Picatinny Arsenal, is responsible for the compilation of data and publishing of the handbook and addenda.

The current guidelines provide a basic understanding of the methods employed in MIL-HDBK-17A to evaluate fiber reinforced plastic composites. A further intention is to assist designers and engineers concerned with the generation of new data. It is urged that the techniques described herein be utilized to the fullest extent. Such a practice will lead to a more comprehensive body of data which can be incorporated into the handbook format. This in turn will result in increased reliability and will permit statistical inferences which are not now possible.

ACKNOWLEDGMENT

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1.0 GENERAL

1.1 Scope of Guidelines: The guidelines contained in this report are concerned with the fabrication, testing, and data handling methods for fiber reinforced composites, such as are documented in MIL-HDBK-17A, Plastics for Aerospace Vehicles, Part I, Reinforced Plastics. A major objective of the guidelines is to standardize the procedures required to evaluate and characterize these composite materials. Attention is focused on polymer based composites containing either woven or non-woven (filamentary) reinforcements.

1.2 Scope and Organization of MIL-HDBK-17A, Part I: MIL-HDBK-17A, Part I is a standardization document prepared and maintained as a joint effort of the Department of Defense, NASA, and the Federal Aviation Administration. Assisting in this effort is a service-industry coordinating group comprised of representatives from various government segments, aerospace manufacturers and material suppliers.

The handbook contains information on the physical and mechanical properties of aerospace quality composites which were prepared and tested under standard conditions approved by the service-industry coordinating group. In addition, the handbook contains background information on the constituent materials and processing methods applicable to aerospace composites. This information has been gathered from numerous sources including material suppliers, aerospace fabricators, and government installations such as the US Forest Products Laboratory.

MIL-HDBK-17A, Part I is organized into the following chapters:

Chapter 1. Introduction contains generalized information pertaining to the succeeding chapters.

Chapter 2. Materials and Processes contains general information on resins, reinforcements, and fabrication processes.

Chapter 3. Design and Analysis of Composites provides an introduction to "elasticity theory" as applied to the analysis and designs of layered composites. It relates previous knowledge of isotropic materials to adaptations of the generalized theory for the analysis of anisotropic layered materials. It also reviews some operations of available computerized design procedures. It is organized as a reference on the effects of anisotropy on composite material properties and is directed primarily to materials engineers and experimentalists.

Chapter 4. Mechanical Properties of Laminates evaluates and tabulates the mechanical and physical properties of aerospace grade materials. Emphasis is placed on evaluations of autoclave cured lay-ups of preimpregnated materials standardized according to government or aerospace company specifications. Conventional tests are conducted on "dry" or "wet" conditioned narrow coupons and after exposures at several temperatures. Graphical results indicate stress-strain relations for the tension, compression and in-plane shear evaluations. Flexural, bearing and interlaminar shear properties are contained as tabulated summaries. Physical properties such as specific gravity, resin content and void content serve to characterize the fabrication process for each laminate. Test results are shown as plots of specific gravity versus gravimetric resin content. Plots of voids content and volumetric fiber fractions are superimposed over the specific gravity versus gravimetric resin content plots.

Chapter 5. Fastening and Joining contains information on adhesive bonding and mechanical fastening of fiber reinforced composites.

Chapter 6. Repair of Reinforced Plastic Structures. Detailed repair procedures are not contained in this chapter; rather, the reader is directed to other sources for such information.

Chapter 7. Quality Control. This chapter has been left blank; it is expected to be issued as a separate addendum to the handbook.

Chapter 8. Non-Destructive Testing provides descriptions for ten non-destructive methods, together with recommended usage and the limitations of each method.

1.3 Material Properties: Composites have had a wide application in the aerospace industry. Satisfactory procedures for evaluating the overall structural behavior of the material are essential. A large portion of the available data was generated in order to compare properties of reinforcing materials and/or resins and is not suitable for use in design and stress analysis.

During the revision of MIL-HDBK-17A, this and other deficiencies became apparent and a more comprehensive approach to evaluating laminates had to be devised and developed. This included the fabrication of test laminates, the determination of the physical and mechanical properties required and the test methods and environmental conditions necessary to obtain these properties for evaluation. The criteria established for the program include:

Mechanical Properties

- Stress-strain relations in tension and compression with uniaxial loads applied parallel (0°) and perpendicular (90°) to the warp or "principal" laminate direction.

- Shear versus shear strain relations with loads applied parallel to the warp and transverse directions, and in the plane of the laminate.
- Poisson's Ratio for (0°) laminates in tension for loads applied parallel to the principal direction and for loads perpendicular to the principal direction.
- Poisson's Ratios for (0° , 90°) and ($0^\circ \pm 45^\circ$, 90°) laminates in tension in (0°) direction only.
- Fatigue-repeated tension, repeated compression and reversed tension-compression loading.
- Interlaminar shear
- Bearing strength
- Flexural strength

Physical Properties

- Resin content
- Specific gravity
- Voids content

Environmental Conditions

- Effects of wet and dry preconditioning on laminate properties.
- Effect of temperature on laminate properties.

1.4 Statistical Evaluation: The objectives of the handbook test program are to obtain statistically significant data for materials currently in use and to determine the degree of reproducibility attained in their fabrication. A minimum requirement is that test results include data from three sets of panels which are representative of the manufacturing procedures employed by three different fabricators. The properties listed in the charts and tables of MIL-HDBK-17A, Chapter 4, generally represent test results from only one set of panels for each material system. Properties are therefore not given minimum values and are considered to be "typical" for each material, and a measure for the scatter of test results is provided. When the minimum number of tests has been completed for a material, its properties will be assigned values on a B-basis; that is, the value above which 90 percent of the population of values is expected to fall with a confidence of 95 percent.

Ranked values will be provided when 30 to 45 test results are available. With more than 45 test results, the statistical values will be reduced in accordance with procedures which assume normal distribution.

2.0 FABRICATION OF TEST PANELS AND SPECIMENS

2.1 General Considerations: To be a candidate for evaluation in MIL-HDBK-17A, a materials system must be standardized to attain reproducible properties in aerostructures. The major characteristics of such materials systems are (1) uniform distribution and controlled quantities of the constituents and (2) a manageable handling and processibility so that cost competitive structures can be fabricated in production facilities. The most readily standardized materials are the "prepregs" which are laid-up and autoclaved cured without significant alterations in polymer/reinforcement ratios or polymer distribution.*

2.2 Preimpregnated Materials: All test panels are fabricated from prepregs. Emphasis is placed on materials for use as facings in sandwich type structures. The prepregs for facings are normally processed to conform with two methods of sandwich fabrication. These are the laminate grades for two-step sandwich constructions and the controlled flow adhesive grades for one-step sandwich constructions. Only laminates simulating precured facings, that is, for use in two-step sandwiches, have been subjected to the narrow coupon tests listed in the MIL-HDBK-17A. The controlled flow prepregs are best tested as sandwich panels, and such testing is not at present included in the handbook program.

The prepreg materials comply with the specifications established by the individual fabricators. In general, the materials are autoclave molding grades with flows controlled to attain minimum bleedout and optimum bonding of the plies. When possible, handling characteristics are specified consistent with the objectives of collimated plies in the laminate and the retention of fiber orientation during layup and cure.

Prepregs are required to attain storage lives of at least six months with an additional out time of at least eight days. Although prepregs may be stored at sub-freezing temperatures, they must be brought to equilibrium at the ambient temperature of the lay-up room

*Handbook data is based on such materials with the exception of data for some fiberglass-polyester laminates taken from earlier sources, and for boron-epoxy panels which were evaluated under contract (Ref 1).

after removal from storage. During the out time, the desired handling and fabrication characteristics must be maintained without effects on the reproducibility of the properties attained in the cured composite.

Fabrication of prepreg materials requires close control to attain optimum properties in the composite. Process objectives are to achieve optimized conditions at the constituent interface, stable cured conditions, dimensional control, reduction of voids, and uniform distribution of optimum constituent contents. In regard to the prepreg systems, these objectives imply control of optimum reinforcement volume fractions and the control of resin bleedout during cure.

The thin (less than one-eighth inch thick) facing laminates are best optimized if fiber volume fractions are maintained as follows:

- 1) Woven fiberglass reinforced laminates: $52\% \pm 5\%$.
- 2) Parallel fiber reinforced laminates (excluding boron fiber): $60\% \pm 5\%$.
- 3) 4 mil boron fiber reinforced laminates: $50\% - 52\% \pm 3\%$.
- 4) Other fiber reinforcements (including Kevlar 49) have not as yet been optimized.

Imposed tolerances on the gravimetric resin content of the prepregs are dependent on the type of reinforcement. For bidirectional woven broadgoods such as style 7781 fabric, the resin fraction is specified as not varying by more than two percent from the assigned devolatilized resin content. For directionally woven broadgoods such as style 7743 fabric, and all other non-woven parallel fiber tapes such as XP251S, variation from the assigned devolatilized resin content is not to exceed three percent.

The uniform distribution of constituents versus low void content appears to be best optimized if less than two percent by weight of the devolatilized resin content is bled from the prepreg during fabrication. Preliminary results indicate that bleedouts of less than one-half percent are optimum for the "hybrid" composites.

The handling characteristics for the prepreg are specified within the following limits:

- 1) Successive layers of prepregs should be separated by release film or paper.
- 2) The release film should be sufficiently strong and stiff to serve as a backing for the prepregs.
- 3) The prepreg should be tacked flat against the backing.

- 4) The resin should be sufficiently advanced so that when the backing is removed only negligible traces of resin remain on the backing.
- 5) The tack of the advanced resin should be sufficient for the prepreg to adhere to the tool and to itself during the lay-up.
- 6) The prepreg should be sufficiently compliant to conform to the surface against which it is laid up.
- 7) The handling characteristics should remain substantially unchanged during its storage life and out time.

The above limits on handling are readily achieved with conventional epoxy and epoxy novolac systems. Current silicone and polyimide systems can be similarly delineated, although in some instances compromises must be negotiated to overcome some deficiencies in handling qualities.

Polyester based prepregs continue to be developed and are expected to be used more frequently in aerospace applications. The physical characteristics of the polyesters cover a broader range and require adjustments to attain the desired handling features. Control of amount and type of monomer is indicated as a necessary requirement to maintain tack and flow properties.

2.3 Woven Fabric Test Panels: The laminates reinforced with woven fabric are presumed to be laid up of 38 inch wide prepregs. Wider prepregs may result in poorer resin-reinforcement distribution. While some wider prepregs have been used for handbook evaluations, these have required prior approval by the service-industry coordinating group. The minimum size for the laminates is two feet parallel to the warp direction by three feet parallel to the prepreg width. When wider prepreg rolls are used, the minimum panel size shall be increased to 36 inches by 46 inches with the 36 inch length parallel to the warp direction.

Test panel thicknesses are determined exclusively by the constituent content fractions and the number of plies they contain. The target volumetric fiber volume fraction for fabric reinforced test laminates is 50% to 55%. The "E" fiberglass reinforced test laminates containing 1581, 7781, and 7743 type fabrics are eight plies thick. The "S" fiberglass reinforced test laminates containing 81-994S/904 fabric are also eight plies thick. The "S" fiberglass reinforced test laminates containing 3405-1014/S24 fabric are twelve plies thick.

The standard lay-up of the fabric reinforced panels is controlled to minimize the anisotropic effects of fill fibers in a skew direction to the fill fibers in the adjacent ply. The procedure is initiated by

designating the prepreg surface containing the satin shafts parallel to the warp as the reference face. One selvage is arbitrarily chosen as the reference edge. First, lengths of prepreg required for each ply are flagged one inch from the reference selvage and at the required length intervals beginning one inch from the original cut end of the prepreg. The flags are successively numbered for each ply. After the flags are positioned on each successive ply, the required total length of prepreg is cut off.

Mylar film, at least two mils thick is used for the auxiliary backing for the even numbered plies. These sheets of film are cut to a size sufficient to cover the whole surface of the plies. Before the original backings for the even numbered plies are removed, the auxiliary backings are positioned and firmly adhered to the prepregs. Then the original backing is removed only from the even numbered plies.

The panel is laid up by tacking the successive layers to the stack before the backings are removed. Upon completion of the lay-up, the outer surfaces should contain the reference faces of the outer plies, the successive pairs of plies should be back to back, and the reference edges should coincide on one panel edge. The net effect of this procedure has been described as an "accordion lay-up".

Although the bleeder and bagging systems are optional, they should be consistent with current aerospace industry practice. The vertical bleedout system using one layer of Armalon (a Teflon coated fiberglass fabric) for the breather covered by one layer of Tedlar perforated one-half inch on center and one layer of dry 1581 E glass fabric may be used as a reference norm for the eight ply lay-ups.

The lay-ups should be bagged and vented for any of the vacuum bag cures, vacuum augmented autoclave cures or the pressure bag cures. The cure cycles should be the ones recommended for the maximum service temperatures. Included in this requirement are the post cures as recommended for the prepreg resin.

2.4 Lay-Up of Non-Woven Panels: Laminates are fabricated from unidirectional prepreg tapes. No limitations are placed on the tape widths. For tension and compression tests of unidirectional lay-ups, panels are to contain six plies. When cross-ply materials, such as $[0^\circ, 90^\circ]_S$ or $[0^\circ \pm 45^\circ, 90^\circ]_S$, are tested in tension or compression, the panels contain eight plies.

Test specimens for interlaminar shear and flexure are taken from unidirectional laminates and contain a sufficient number of plies to attain 0.1 inch minimum thickness.

2.5 Cure Cycles: The maximum total pressure applied to the lay-up (the differential between vacuum and autoclave pressure) shall not exceed 50 psi. Normally this restriction applies to prepregs with epoxy, polyester, phenolic, or silicone resin systems. A maximum pressure is not specified for other resin systems, such as polyimides and polybenzimidazoles, where higher pressures are generally required.

The resin content of the cured panel may be maintained by controlling the resin content of the prepreg or by a controlled bleedout of the prepreg during cure. When the prepreg resin content is used for control, edge bleedouts are required and bleeder plies serve to reduce the voids content. With resin control by bleedout, the vertical system consisting of a perforated peel ply and a bleeder ply is used and edge bleedout is restricted by flexible dams. The thickness of finished panels is controlled by the number of plies, and the resin content. The use of cover caul plates or adaptations of closed space molding techniques to control the panel thickness is not acceptable.

2.6 Identification of Raw Materials: Information for identifying the prepreg shall be recorded as indicated in Table 1. The table includes the fabricator's test results on resin content, flow and volatiles, as well as results furnished by the prepreg manufacturer.

2.7 Recording of Fabrication Procedures: Details of the fabrication which are to be reported are shown in Table 2. Description of the curing, cooling and post cure cycles will include such information as vacuum pressures, autoclave pressures, temperatures, heating rates, cooling rates, and dwell times at each temperature level.

2.8 Test Specimens Location: Figure 1 represents a plan for locating and numbering the various test specimens in a two feet by three feet panel made from a woven fabric reinforcement. The plan can be readily adapted to a 36 inch by 46 inch panel or to a three feet by two feet panel made from non-woven fabric.

The test blocks can be rough cut from the panel and machined. The finished specimens are to be free of fiber pullouts, rough edges, chipped resin or machining burns.

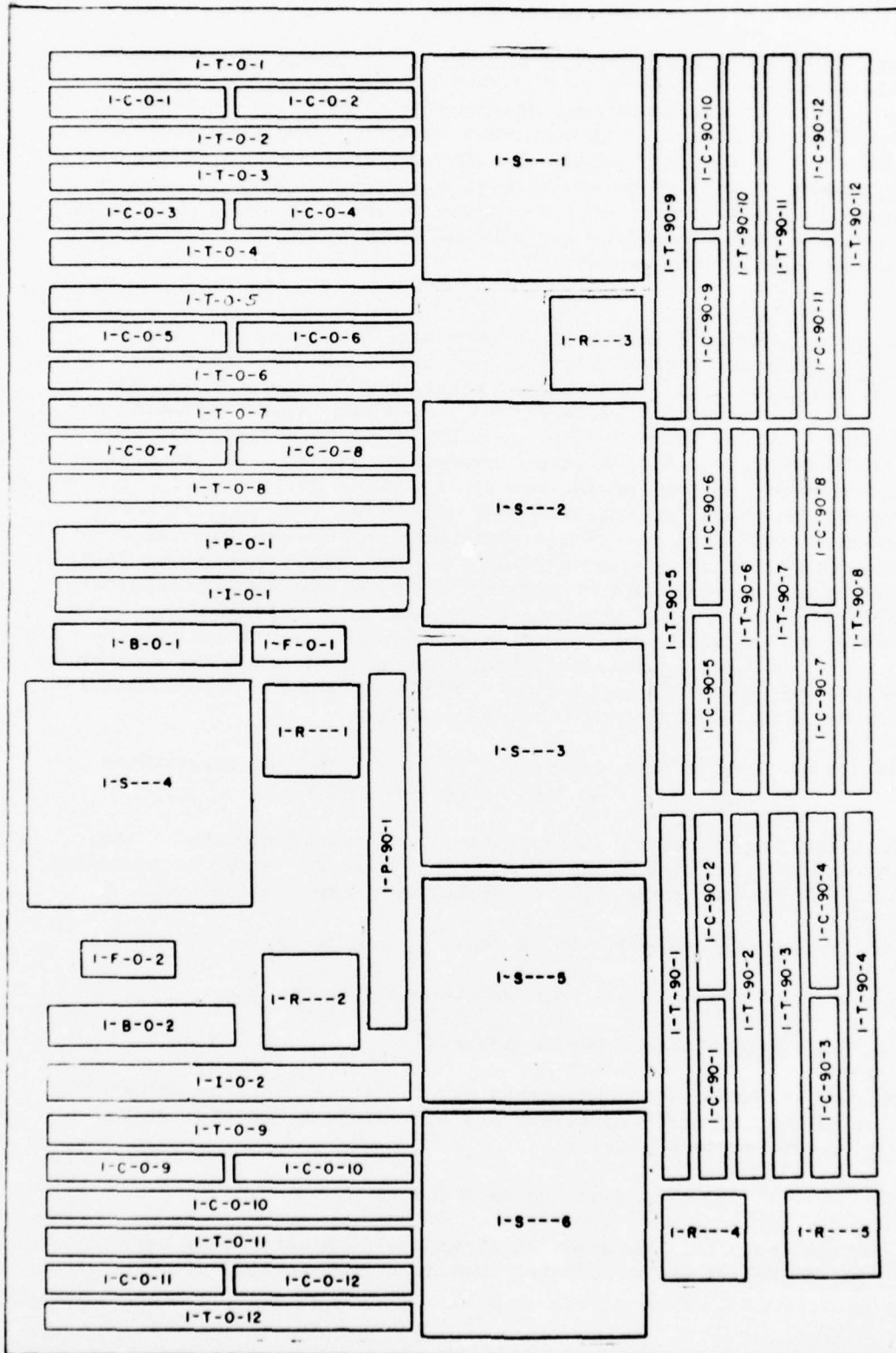
TABLE 1. PREPREG IDENTIFICATION

Manufacturer's Designation	_____
Type Resin	_____
Fabric Style	_____
Resin Content, Weight %	_____
% Flow	_____
% Volatiles	_____
Gel Time	_____
Batch No.	_____
Roll No.	_____
Roll Width	_____
Cured Resin Specific Gravity	_____
Fabric Manufacturer	_____
Fabric Designation	_____
Yarn Count and No.*, Warp	_____
Yarn Count and No.*, Fill	_____
Finish	_____

*Includes type glass, type filament, nominal filament diameter, yards per pound and number of strands to a yarn, i.e., ECDE-75-1/0.

TABLE 2. FABRICATION OF LAMINATES

Material	-----
Fabricator	-----
Date	-----
No. of Plies	-----
Direction of Plies	-----
Ply Sequence	-----
Edge Bleedout	-----
Vertical Bleedout	-----
Nominal Panel Size	-----
Temp. Press Room	-----
Relative Humidity-Press Room	-----
Cure Heating Cycle	-----
Cure Conditions	-----
Cooling Cycle and Quench	-----
Postcure Cycle and Quench	-----



T = Tensile C = Compression S = Panel Shear P = Poisson's Ratio
 F = Flexure B = Bearing I = Interlaminar Shear R = Percent Resin & Specific Gravity

Figure 1. Test Specimen Location in 2 Ft. by 3 Ft. Panel

3.0 Test Procedures for Woven and Non-Woven Laminates: The attempt has been made to select standardized test procedures whenever such tests are found to yield reproducible results in material evaluations and when they are in accord with current aerospace industry practice. In certain tests, standardization has not been achieved and it has become necessary to make arbitrary selection. However, these selections are generally based on preliminary studies in which the effects of test variables have been enumerated and have been confirmed by a series of comparative tests (round robins).

3.1 Tension: Three different specimens were evaluated for tension testing of glass reinforced plastics (Ref 2). These specimens are (1) ASTM-D638 Type 1, (2) a tab ended straight side specimen and (3) a modified bow tie (long necked) specimen. Specimens were evaluated with resin content of 24, 32, and 36 percent by weight from laminates made with HEXCEL F-161/7781-550, a fiberglass-epoxy prepreg. The strength and stiffness of the long necked bow-tie specimens were equal to or superior to the other two specimen configurations. The failure mode of the long necked specimens was consistently within the gauge area, while the other shaped specimens failed in areas where the stress level was thought to be lower than at the center of the specimen. To evaluate the ASTM-D638 specimen failure mode at the shoulder radius, a series of modified specimens were prepared. The modification was to change the shoulder radius from the standard three inch to both eight and eighteen inches. These radius changes did not shift the location of the failures, that is, failures still occurred at the shoulder.

Table 3. Tensile Strength versus Specimen Geometry illustrates the difference obtained by the three types of specimens.

As a result of these investigations, the tensile strength tests for woven-fabric (bi-directional) laminates shall be performed according to ASTM-D638, Tensile Properties of Plastics, except as follows:

- 1) Test specimens shall be as shown in Figure 2a.
- 2) Rate of strain shall be 0.018 to 0.024 inches/minute.
- 3) Gage length should be two inches.
- 4) The recorded load and strain magnification shall be adjusted so that 10 scale divisions are equivalent to 10,000 psi and 0.005 inches of strain.
- 5) Load deformation shall be recorded to break.

Tensile tests for non-woven (directional) laminates have been investigated (Ref 3) and procedures have been incorporated into

Table 3. Comparison of Tensile Tests, Tensile Strength versus Specimen Geometry (Ref 2)

Type	Dimensions, in.			E, ksi			E, 10 ⁴ psi			Lam- ina- S/N	Warp Direc- tion, deg	Rena Contd., %	Failure Remarks
	Length	Gage Width	Radius	A ₁	Low	High	A ₂	Low	High				
PHASE I TESTS													
ASTM D 638.....	8½	0.500	3	55.9	...	...	...	...	...	3	0	36.1	100% in radius area
ASTM D 638.....	8½	0.500	3	42.6	40.6	43.8	3.40	3.33	3.51	90	3	36.1	100% in radius area
ASTM D 638.....	8½	0.500	3	55.9	54.8	56.6	3.75	3.65	3.94	4	0	36.2	100% in radius area
ASTM D 638.....	8½	0.500	3	44.5	43.8	45.1	3.45	3.27	3.62	4	90	36.2	100% in radius area
ASTM D 638.....	8½	0.500	3	46.3	44.5	48.8	3.43	3.35	3.51	6	90	34.8	100% in radius area
Tab ended ^a	10½	0.500	straight length	52.1 ^a	51.9	52.3	3.46	...	...	4	0	36.2	100% in tab area
Tab ended ^a	10½	0.500	straight length	61.0 ^a	...	...	...	...	...	4	0	36.2	100% in tab area
Tab ended ^a	10½	0.500	straight length	33.5	32.3	35.5	3.23	3.14	3.38	4	90	36.2	100% in tab area
Tab ended ^a	10½	0.500	straight length	60.8	59.4	62.0	2.73	...	...	4	0	36.2	100% in tab area
PHASE II TESTS													
ASTM D 638.....	8½	0.500	3	73.7	70.7	76.7	...	...	...	8	0	24.2	100% in radius area
ASTM D 638.....	9¼	0.500	8	72.6	70.1	75.2	...	...	...	8	0	24.2	100% in radius area
ASTM D 638.....	11½	0.500	18	73.9	73.0	74.8	...	...	...	8	0	24.2	100% in radius area
Long neck ^a /.....	8½	0.500	tapered neck	78.1	74.9	82.1	4.61	4.49	4.78	8	0	24.2	75% in gage area
Long neck ^a /.....	11½	0.500	tapered neck	79.7	76.5	83.3	4.58	4.36	4.76	8	0	24.2	100% in gage area
Tab ended ^a /.....	10½	0.500	straight length	64.2	62.8	65.7	4.58	4.19	5.07	8	0	24.2	100% in tab area
Tab ended ^a /.....	9	0.500	straight length	52.5	52.8	57.7	...	...	...	8	0	24.2	100% in tab area
Long neck ^a	8½	0.250	tapered neck	73.5	70.7	76.2	5.10	4.90	5.20	8	0	24.2	100% in gage area
Long neck ^a	11½	0.250	tapered neck	76.9	76.3	77.5	4.40	4.36	4.43	8	0	24.2	100% in gage area
PHASE III TESTS													
Long neck ^a /.....	8½	0.500	tapered neck	72.6	71.9	73.0	3.78	3.76	3.80	10	0	32.2	100% in gage area
Long neck ^a /.....	8½	0.500	tapered neck	72.6	71.9	73.0	4.48	4.37	4.55	10	0	32.2	100% in gage area
Long neck ^a /.....	11½	0.500	tapered neck	75.3	74.0	77.0	3.60	3.42	3.79	10	0	32.2	100% in gage area
Long neck ^a /.....	11½	0.500	tapered neck	75.3	74.0	77.0	4.20	4.17	4.23	10	0	32.2	100% in gage area
Long neck ^a /.....	8½	0.500	tapered neck	67.2	59.5	72.2	3.74	3.54	3.99	6	0	34.8	100% in gage area

^a Partial grip in machine jaws.

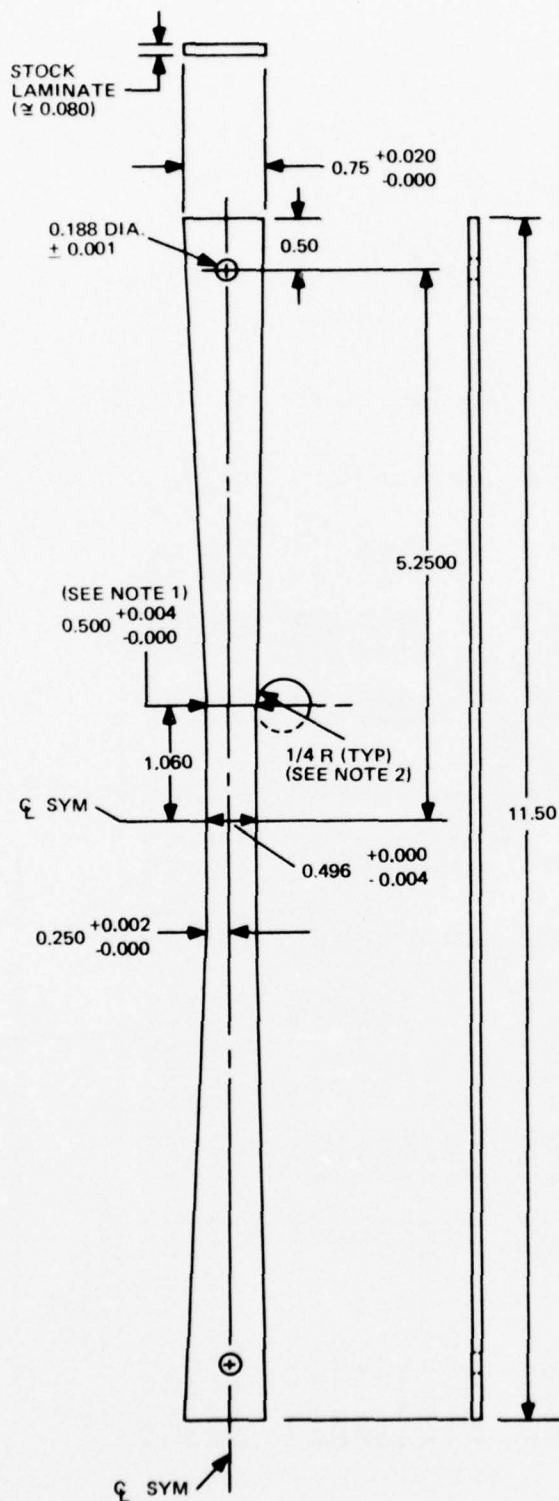
^b Full grip in machine jaws.

^c Fiber glass tabs.

^d ABS plastic tabs.

^e See Figs. 2 & 7.

/ Extensometer is placed on edges of specimen. All others are face mounted.



NOTES:

1. THE WIDTH OUTWARD FROM 0.496 SHALL BE INCREASED GRADUALLY AND EQUALLY ON EACH SIDE UP TO 0.500 SO THAT NO ABRUPT CHANGES IN DIMENSIONS RESULT.
2. TRANSITION FROM STRAIGHT-SIDED CENTER SECTION TO TAPERED SECTION SHALL BE SMOOTHLY JOINED IN THE AREA OF THE 1/4 RAD.

Figure 2a. Tensile Specimen, Woven Fabric

ASTM-D3039, Tensile Properties of Oriented Fiber Composites. Tests for tensile strength of directional laminates are therefore conducted according to ASTM-D3039 with the following exceptions:

- 1) Test specimens for non-woven (directional) laminates shall be as shown in Figure 2b.
- 2) Rate of strain shall be 0.018 to 0.024 inches per minute.
- 3) Gage length shall be two inches.
- 4) The recorded load and strain magnification shall be adjusted so that 10 scale divisions are equivalent to 10,000 psi and 0.005 inches of strain for fiberglass. With the high modulus, low elongation materials, the magnifications are adjusted so that the stress-strain plot is at an angle of from 45° to 60° with the strain axis.
- 5) Load deformation shall be recorded to break.

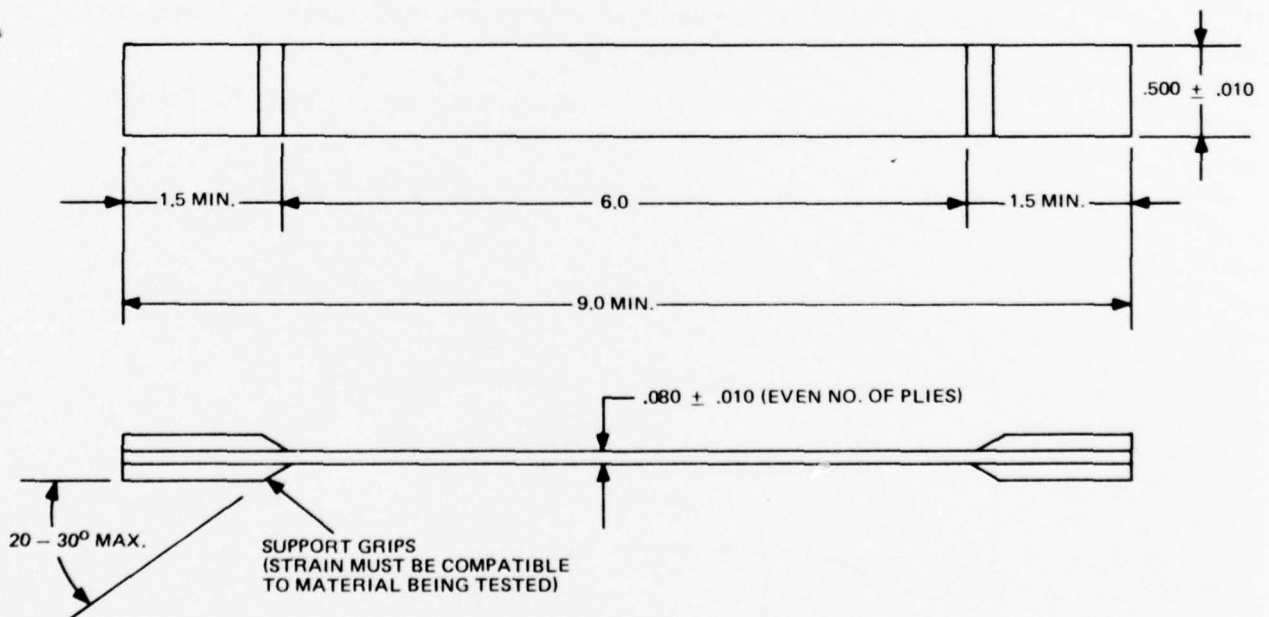


Figure 2b. Tensile Specimen, Non-Woven Laminate

3.2 Compression: Compressive test method may be characterized by both the method of applying the load to the test area and the means of stabilization used. There are two principal loading procedures: direct end loading of the specimen and beam bending.

Compression modes of failures for plates, sandwich specimens and panels can have a different strength, and compressive failure will occur at the lowest strength mode existing in the specimen. Thus, compressive strength is not a precise term but may refer to any one of several modes of failure, each with its related strength mode. Basic material compressive strength generally refers to the value obtained when the specimen is so thick and/or so short that no stabilization is required. In filamentary composites, such basic compressive failures would take the form of filament fracture, failure of material stabilization, matrix failure, or layer instability.

The two best methods selected for compressive tests are:

Woven Bidirectional Fabric Laminates Tested in 0° or 90° Direction and Non-Woven Laminates Tested in the 90° Direction

Compressive strength shall be performed according to the requirement of ASTM-D695 Compressive Properties of Rigid Plastics, except as follows:

- 1) Test specimens for woven laminate fabric bidirectional laminates shall be as shown in Figure 3.
- 2) Test specimens of non-woven laminates tested in the 90° direction shall also be as shown in Figure 3.
- 3) The specimen support jig shall be as shown in Figure 4.

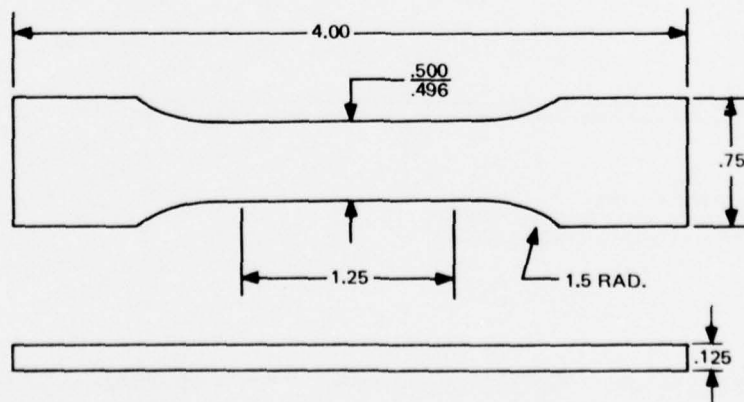
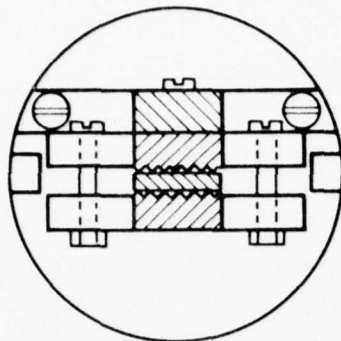


Figure 3. Bidirectional Fabric Compression Specimen



SECTION AA

NOTE: TEFLON FACING MAY BE USED IN PLACE OF GROOVED STEEL FACINGS SHOWN.

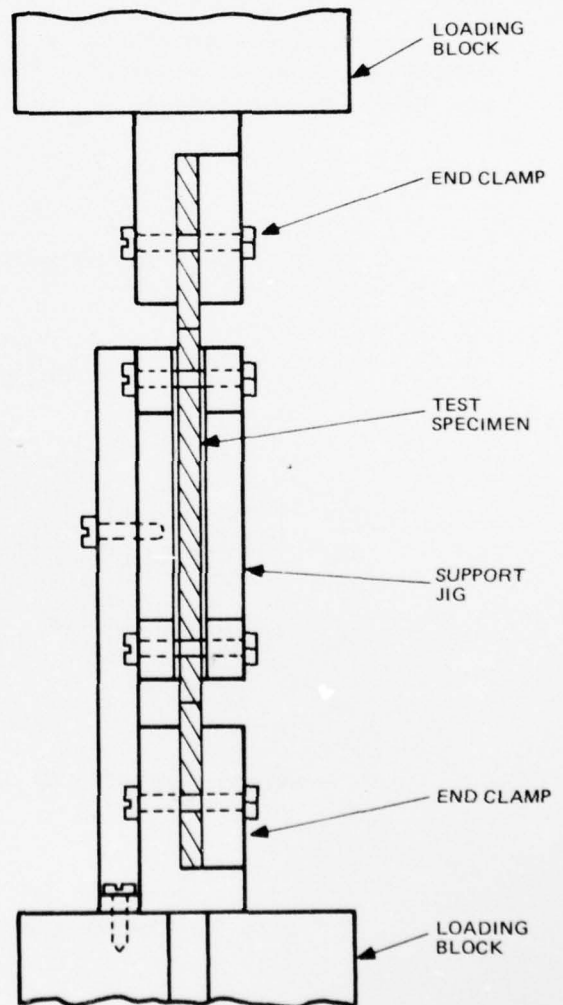
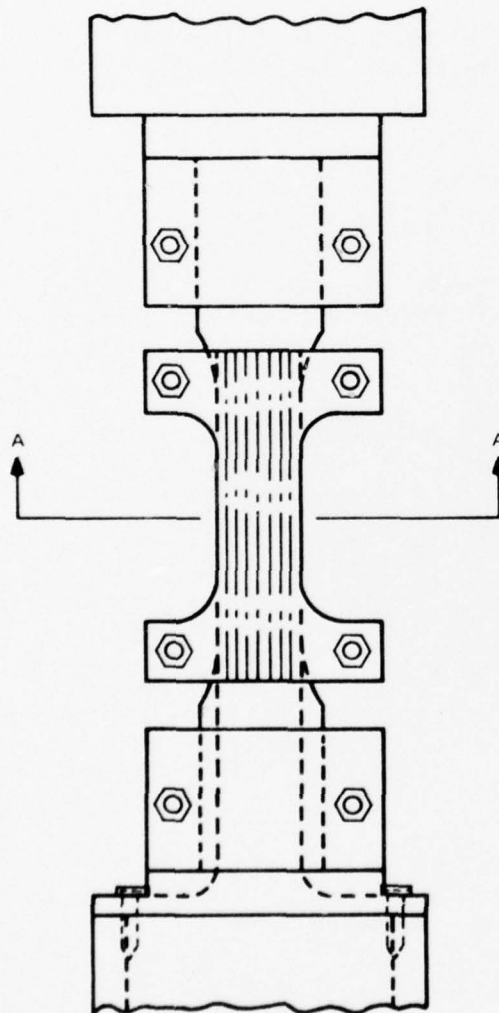


Figure 4. Serrated Support Jig

- 4) Strain measurements shall be made using extensometer attached to the specimen at a one inch gage length. The method of using cross head movement for measuring strain is not acceptable.
- 5) The strain rate shall be 0.018 - 0.024 inches/minute.
- 6) The recorded load and strain magnification shall be adjusted so that 10 scale divisions are equivalent to 10,000 psi and 0.005 inches of strain.
- 7) Load deformation shall be recorded to break.

Non-Woven Laminates Tested in the Direction of the Fibers
(0° Direction)

Compressive strength shall be performed by the "Sandwich Beam Method" as shown in Figure 5. Further details of this test method are given in Reference 4.

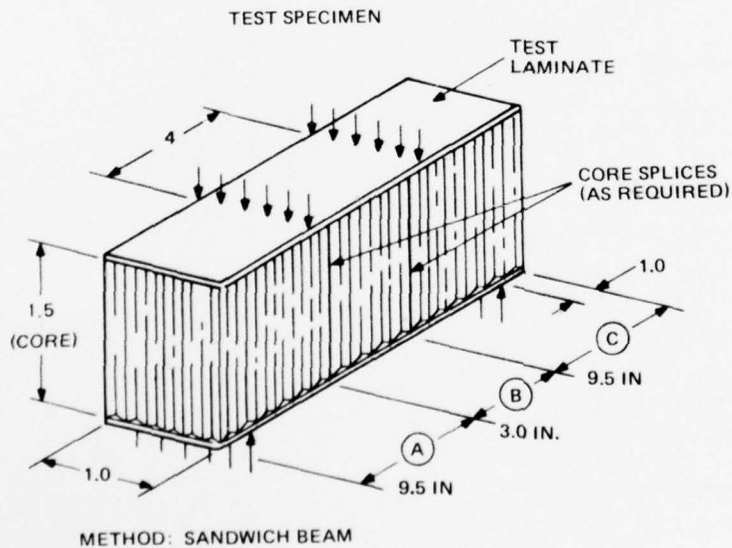


Figure 5. Compression Specimen - Sandwich Beam

3.3 Intralaminar Shear Properties (In-Plane Shear)

3.3.1 Rail Shear Method (Ref 5): This method is a procedure using a modified picture frame called the "rail shear test". It uses a thin laminate, 1/16 to 1/8 inches thick, 3 inches wide by 6 inches long, supported along the six inch length by two pair of rails, leaving a 1/2 inch-wide unsupported central section. A compressive load is applied to the specimen diagonally along the rails. Parts of this reference are contained in Appendix 1.

1) Test Specimens: Test specimens shall conform to the dimensions shown in Figure 6. These specimens have a net section for shear distortion 1/2 inch wide by 5 inches long and a net section for shear strength 5 inches long by the thickness of the laminate. The 5-inch dimension may be (1) parallel to the principal fiber direction for 0°-90° intralaminar shear characteristics, (2) perpendicular to the fiber direction for 90°-0° characteristics, or (3) at 45° to the fiber direction for -45° characteristics, depending on the angle for which shear characteristics are desired.

The linear edges of the specimen may have coarse tool marks from the machining operation; however, the holes should be drilled and reamed and the 1/2 inch radius shaping at the extremity of the net section shall be finished with a diamond or emery wheel.

2) Speed of Testing: The speed of testing shall be 0.04 to 0.06 inches per minute unless otherwise specified.

3) Intralaminar Shear Strength: Calculate the shear stresses and shear strength as follows:

$$T = \frac{P}{lt} \quad \text{(Equation 1)}$$

where:

T = shear stress, psi

P = load on the rails, pounds

l = length of specimen, inches

t = thickness of specimen, inches

4) Intralaminar Shear Strain: Calculate or observe directly, if possible, the detrusion or tangent of the angular change between two lines originally perpendicular to each other through a point in the specimen. Such detrusion is measured in radians.

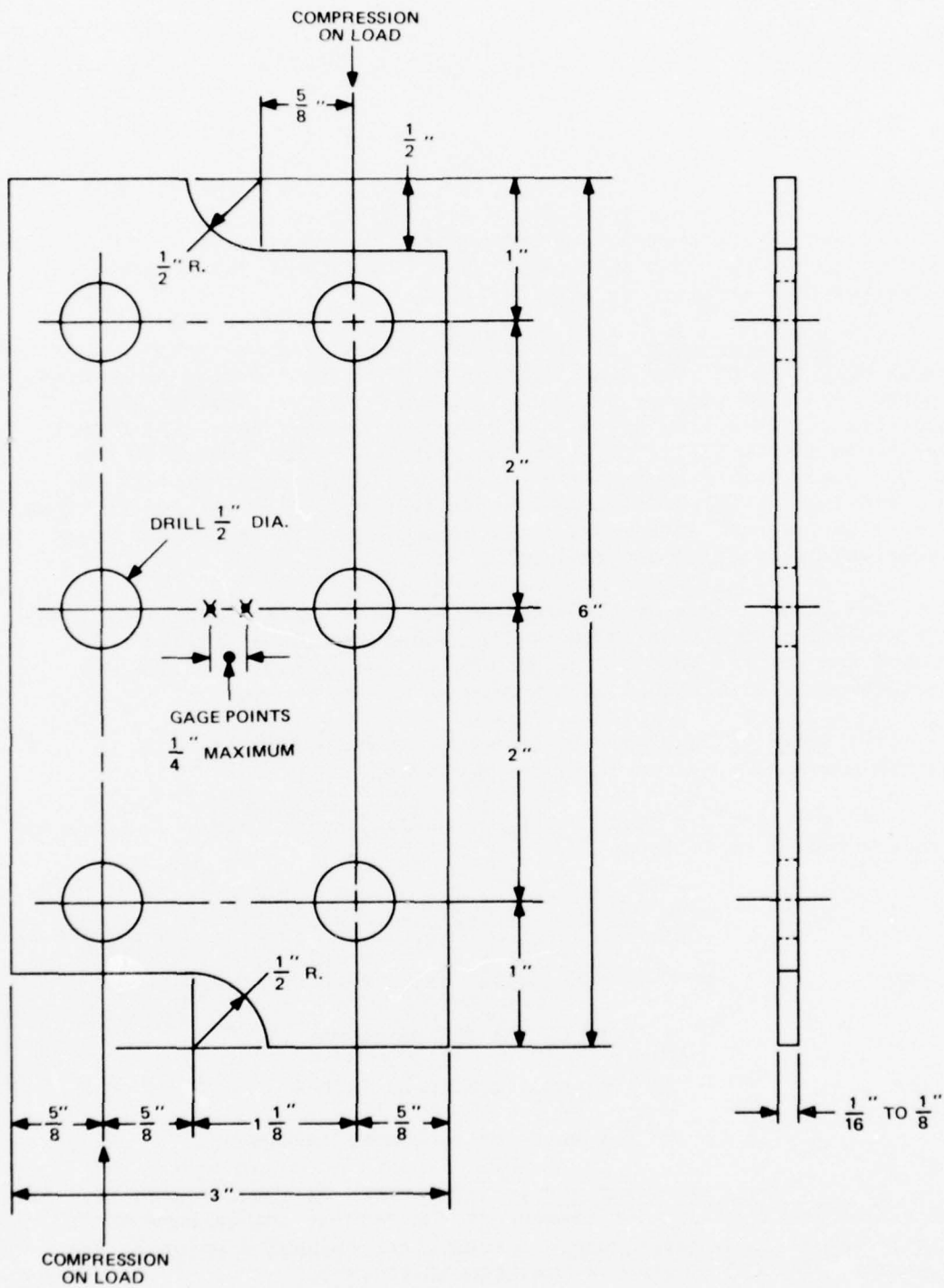


Figure 6. Rail Shear Specimen

5) Modulus of Rigidity: Calculate the slope of the initial tangent modulus of rigidity (G_{yx}) in intralaminar shear, as follows:

$$G_{yx} = \frac{T}{O} = \frac{P' \overline{AO}}{lt \overline{AB}} \quad (\text{Equation 2})$$

where:

P' = load at elastic limit, pound

O = detrusion in radians, inches/inch

\overline{AO} = gage point distance, inches

\overline{AB} = distortion, inches

3.4 Poisson's Ratio: Poisson's Ratio in Tension shall be determined as described in Reference 6 with the following exceptions:

1) The specimen shall be one inch wide by 9-1/2 inches long. For elevated temperature tests, it may be necessary to use shorter specimens if the heating cabinet cannot accommodate this length.

2) An extensometer shall be centrally located to measure longitudinal extensions, and strain gages centrally located to measure lateral contractions.

3) Determination of Poisson's Ratio shall be made on the initial loading cycle only.

4) Loading shall be to approximately 75% of ultimate strain as determined by the tensile test.

5) Extension and contraction shall be continuously recorded. Other details shall comply with ASTM-D638.

3.5 Interlaminar Shear: Interlaminar shear tests for fiberglass composites have been conducted according to ASTM-D2733, Interlaminar Shear Strength of Structural Reinforced Plastics at Elevated Temperatures, Method A. However, it is recommended that these tests be conducted for fiberglass as well as other reinforcements such as boron, graphite, and Kevlar according to ASTM-D2344, Apparent Horizontal Shear Strength of Reinforced Plastics by Short Beam Method.

3.6 Flexure: Flexural strength for reinforced laminates shall be performed in accordance with ASTM-D790, Flexural Properties of Plastics.

3.7 Bearing: Bearing strength tests shall conform to ASTM-D953, Bearing Strength of Plastics.

3.8 Specific Gravity: Specific gravity shall be determined by ASTM-D792, Specific Gravity and Density of Plastics by Displacement, (Method A).

3.9 Resin Content

3.9.1 Fiberglass Reinforced: Resin content shall be determined by ASTM-D2584, Ignition Loss of Cured Reinforced Resins.

3.9.2 Boron, Graphite, and Kevlar: Resin content for boron, graphite, and Kevlar are determined by the method of ASTM-D3171, Fiber Content of Reinforced Resin Composites. See also Reference 7.

3.10 Void Content: The void content shall be determined by ASTM-D2734, Void Content of Reinforced Plastics.

3.11 Test Schedule and Conditioning

Tests: The specific tests, number of specimens to be tested, prior conditioning, test temperatures, and laminate test directions are shown in Table 4.

Test Temperatures: Test temperatures shall be -65°F , 75°F , 160°F , T_{max} and $T_{\text{max}} + 50^{\circ}\text{F}$. T_{max} is the maximum temperature a material can stand for 100 hours of service without evidence of deterioration.

Test Conditioning (See Appendix 2)

Dry State: The dry state is attained by conditioning specimens at 45-55 percent relative humidity at a temperature of from 70°F - 75°F for fourteen days.

Wet State: The wet state is attained by subjecting specimens to an atmosphere of 100 percent relative humidity at 125°F for 42 days.

Tests at -65°F Dry State: Specimens are conditioned for one-half hour at -65°F prior to testing at that temperature.

Wet State: Specimens are conditioned at -65°F for one-half hour, returned to 100 percent relative humidity at 125°F for one-half hour, cycled four times and finally conditioned for one-half hour at -65°F prior to testing at that temperature.

Tests at 160°F and $T_{\text{Max}} + 50^{\circ}\text{F}$: Specimens are conditioned for one hour at the test temperature prior to testing.

TABLE 4. TEST SCHEDULE FOR TYPE I AND TYPE II LAMINATES

Test	Direction - °	Condition	Number of Specimens			
			Type I and Type II		Type II	
			Ambient	-65	160	T _{max}
Tension	0	dry	10	10	10	10
Tension	90	dry	10	10	10	10
Tension	0	wet	10	10	10	--
Tension	90	wet	10	10	10	--
Compression	0	dry	10	10	10	10
Compression	90	dry	10	10	10	10
Compression	0	wet	10	10	10	--
Compression	90	wet	10	10	10	--
Shear	0-90	dry	10	10	10	--
Flexure	0	dry	5	5	5	5
Interlaminar Shear	0	dry	5	5	5	5
Bearing	0	dry	5	5	5	5
Poisson's Ratio	0-90	dry	5	--	--	--
Poisson's Ratio	90-0	dry	5	--	--	--

Type I - General Purpose Laminates

Type II - Laminates for Elevated Temperature Use

Percent Resin - 5 tests per panel

Percent Voids - 5 tests per panel

Specific Gravity - 5 tests per panel

3.12 Reporting of Data: Data shall be summarized as shown in Table 5. The properties and data for the various tests listed are to include the following:

Resin Content, Specific Gravity, and Percent Voids: Record individual readings and average for each panel.

Tensile, Compressive and Shear Properties: Record individual load-deformation curves or stress-strain curves to break, specimen dimensions and panel identification. The average tensile and compressive strengths and elongation at break and shear strength shall be reported with standard deviations.

Poisson's Ratio: Curves showing Poisson's Ratio versus Extension in the longitudinal direction for all specimens tested shall be reported.

Flexural Properties: Load-deflection curves on all samples and average flexural strength and initial modulus shall be reported.

Bearing Properties: Load at four percent deformation of hole diameter and at failure shall be reported.

Interlaminar Shear: Report specimen dimensions and load at failure.

4.0 PRESENTATION OF DATA

4.1 Graphical Presentation: Uniaxial tension, compression and shear are shown as stress-strain relations at each temperature. Poisson's Ratio is shown as the response of the 0° elongation and 90° contraction to the applied tensile stress.

When 10 or more results are available at a test condition stress-strain relations are plotted as an average curve and a plot of the average minus three times the standard deviation is also shown. When five to nine results are obtained from a test condition, average, maximum and minimum values are plotted.

4.2 Tabular Presentation: Uniaxial tension, compression shear, flexure, bearing and interlaminar shear data are listed in summary tables at each test condition as well as the fabrication conditions and the physical properties of the laminates.

TABLE 5. SUMMARY OF MECHANICAL PROPERTIES

Composite

Identification	Reinforcement		Resin		Finish	
Fabrication	Method		Pressure		Cure Post cure	
Thickness	Plies inches					
Physical Properties	Percent Resin		Specific Gravity		Percent Voids	
Temperature	-65 ^o F		75 ^o F		160 ^o F	
Condition	Dry	Wet	Dry	Wet	Dry	Wet

Av. Tensile Properties

0° ksi
 90° ksi
 Initial Modulus
 0° psi x 10⁶
 90° psi x 10⁶
 Elongation at Break
 0° percent
 90° percent

Av. Compressive Props

0° ksi
 90° ksi
 Initial Modulus
 0° psi x 10⁶
 90° psi x 10⁶
 Elongation at Break
 0° percent
 90° percent

Av. Shear Props

Strength ksi
 Modulus psi x 10⁵

Poisson's Ratio

0°, 90°
 90°, 0°

Flexural Properties

Strength ksi
 Initial Mod. psi x 10⁶

Bearing Properties

Strength 4%
 Strength, Break

Interlaminar Shear, ksi

5.0 PROPERTIES OF CONSTITUENT MATERIALS: Chapter 2 of MIL-HDBK-17A describes the various resin systems and reinforcements used in composites and gives the applicable specification for determining the mechanical, physical and electrical properties of the constituents.

6.0 TEST METHODS OF JOINTS AND ADHESIVES: Information is provided in Chapter 5 of the Handbook on joints fabricated by adhesive bonding, mechanical fastening or a combination of both types. References are given for design and analysis procedures for joint design. Summary data for various joints and adherents have been compiled from basically two sources and are included in Chapter 5 of MIL-HDBK-17A.

Test methods for joining composite materials are currently being reviewed and it is anticipated that they will be incorporated in this chapter of the Guidelines and MIL-HDBK-17A.

7.0 TEMPERATURE EFFECTS ON PROPERTIES: Normally the properties of composites are reduced as the temperature increases. The high temperature testing of composites introduces several important variables.

- 1) Testing laminates above their cure temperature can cause secondary changes (such as increases in crosslinking) which will affect their properties to an extent which depends on the length of time of exposure to elevated temperature.

- 2) The low thermal conductivity of many composites has a direct relationship to the "soak-time" and may not reflect the true conditions of the mechanical properties at the elevated temperatures.

Data in MIL-HDBK-17A is normally provided for the temperature range of -65°F to 160°F . Several materials have been tested at 400°F and the data is presented for these materials which were tested for 50°F plus maximum service temperature of 350°F .

8.0 FATIGUE: The current revision of MIL-HDBK-17A contains some summary fatigue data on adhesive joints taken from the literature.

The absence of fatigue data in the current revision of MIL-HDBK-17A does not mean this type of data will not be presented in future revisions of the Handbook, but rather that difficulties are being encountered with the validity and type of test specimens and test

methods to be used for generating this data. Until these problems are resolved the generation of fatigue data will be restricted to dry conditioned specimens fatigue tested at standard conditions for the stress ratio of 0.1. The constant amplitude stress test will be conducted at 30Hz.

9.0 STATISTICAL PROCEDURES

A-Basis - The A-Mechanical property value is the value above which at least 99 percent of the population of values is expected to fall, with a confidence level of 95 percent.

B-Basis - The B-Mechanical property value is the value above which at least 90 percent of the population of values is expected to fall, with a confidence level of 95 percent.

At the current time when ten or more results are available at a test condition, average values and the associated standard deviation are given in the tables. Stress-strain relations are plotted as an average curve and a plot of the average minus three times the standard deviation is also shown. When five to nine results are obtained from a test condition, average maximum and minimum values and curves are shown.

B-Basis values will be developed and included in the Handbook. The test stresses for the materials will be calculated on the basis of a nominal ply thickness times the number of plies rather than measured thickness. This procedure results in the reduction of test data to a common reference thereby permitting a uniform standard independent of fabrication tolerance. "The Direct Computation for an Unknown Distribution" was used in preparing the data for the Handbook. (Ref 8, 9).

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1. Southwest Research Institute. Boron Fiber Reinforced/Polymer Matrix Composites - Material Properties. G. C. Grimes and C. J. Ovenby, January 1970.
2. Grumman Aircraft Engineering Corp. Determination of Principal Properties of "E" Fiberglass High Temperature Epoxy Laminates for Aircraft. S. J. Dastin et al. DAAA-21-68-C-0404, August 1969. AD 699 362.
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5. Forest Products Laboratory. A Method to Measure Intra Laminar Shear Properties of Composites Laminates, K. H. Boller, AFML-TR-69-311, March 1970.
6. Forest Products Laboratory. Poisson's Ratios for Glass-Fabric Base Plastic Laminates, R. L. Youngs. FPL Report No. 1860, January 1957.
7. E. M. Leone. Evaluation of Test Techniques for Advanced Composite Materials AFML-TR-68-166, Part 11, December 1969. AD 699 586.
8. Engineering Design Handbook. Experiment Statistics. AMC Pamphlet AMCP 706-110, AMCP 706-111, AMCP-112, AMCP-113, AMCP-114, December 1969.
9. Chapter 6, Statistical Procedures, MIL-HDBK-5, Guidelines for the Presentation of Data. Tech Report AFML-TR-66-386. AD 806 651.

APPENDIX A: FPL - SPLIT RAILS EDGEWISE SHEAR TEST PROCEDURE (Ref 5)

Specimen

Use 100 grit emery cloth between rails and specimen. In order to preclude specimen failure in bearing, drill the holes in the specimen overside to 1/2-inch diameter. As an added precaution, position the rail and its bolts in the holes of the specimen so that the bolt is in contact with the specimen on the side opposite to compressive bearing. Torque the bolts to 70 lbs./ft. with the rollers located between rails and lightly clamped to maintain their position. (The rollers add lateral stability to the rails and distribute the forces.) The center pair of bolts should be torqued last.

Use strips of 500 grit emery paper to locate the bearing side of the detrusion gage as per Figure 1A.

Loading

The loading fixture and general test procedure is per the FPL preliminary report* to the Task Force for Test Methods of MIL-HDBK-17. However, a modified detrusion gage as per Figures 1A and 2A is used. The mirror attached to the gage reflects the image of an illuminated curved scale at a 120-inch distance from the mirror (Figure 2A). The image is viewed using a surveyor's transit. The scale used was ruled to .01-inch and the image could be resolved to .005-inch. The shear stress and modulus of rigidity are determined from the equations shown in the FPL report.*

* Use of Experimental Rails to Evaluate Edgewise Shear Properties of Glass-Reinforced Plastic Laminates by L. H. Floeter, Engineering Technician and K. H. Boller, Engineer of the U. S. Forest Products Laboratory, Madison, Wisconsin.

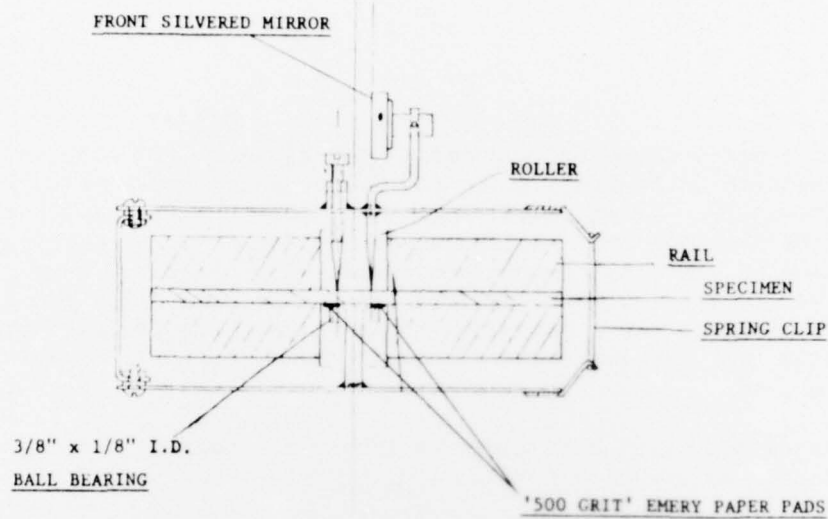


Figure 1A. Modified Detrusion Gauge

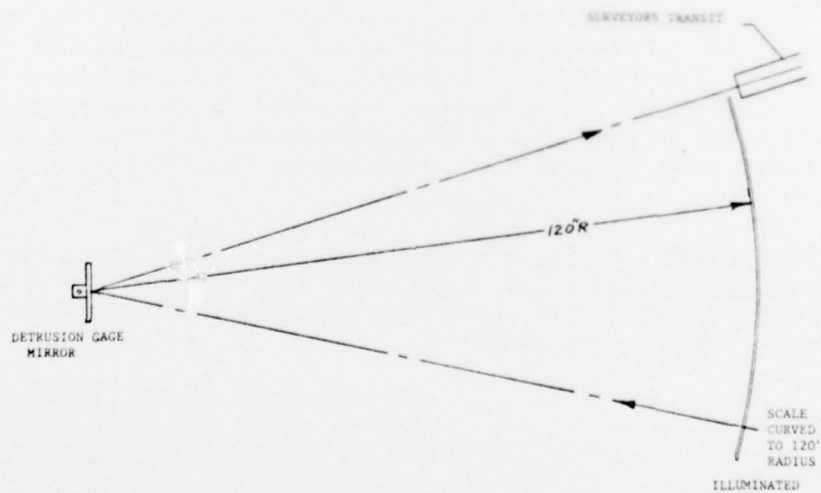


Figure 2A. Rail Shear Test and Schematic of Detrusion Gauge Measurement

APPENDIX B: SPECIMEN CONDITIONING

Conventional tests are conducted on "dry" or "wet" conditioned narrow coupons. Dry conditioned specimens are brought to equilibrium for at least 14 days at 70° to 75°F and 45% to 55% R.H. Upon removal from these standard conditions, the coupons are immediately subjected to exposure at test conditions or to other environmental conditioning as indicated in the data requirements.

Unless otherwise noted, dry specimens are exposed to the test temperature for 1/2 hour prior to the test. Initially, the test cabinet is allowed to come to thermal equilibrium at the test temperature. The ambient moisture content of the air is allowed to prevail. The timing for exposure to the test temperature is initiated immediately upon insertion of the specimens into the opened cabinet. The thermal inertia of the test cabinet should be sufficient to recover equilibrium with the test temperature within 15 minutes.

When longer times for exposure are required, specimens may be aged in cabinets other than the test chambers. On those occasions, the transfer of specimens from the auxiliary chambers to the test cabinet must be accomplished so that the specimen surface temperature remains within the specified tolerance. In any event, the tests are conducted at the indicated temperature. Room temperature properties of specimens exposed at elevated temperatures are not normally required. Those evaluations are compiled as data on special environments.

Wet conditioned specimens are subjected to 95% to 100% relative humidity at 125°F for 1000 hours or 42 days. Immediately upon removal from the saturated conditions the coupons are subjected to either the required temperature cycling or the test conditions. Wet specimens tested below 32°F are cycled four times between the saturated conditions at 125°F and the test temperature. The addition of moisture to below freezing atmospheres is avoided.

Upon removal from the saturated conditions at 125°F the specimens are held for 1/2 hour at the sub-freezing test temperature. Then the specimens are again returned to the saturated conditions at 125°F for another 1/2 hour. The specimen is tested after exposure to the sub-freezing test temperature for 1/2 hour for the fourth time.

Saturation conditions are maintained at test temperatures between 32°F and 200°F. Within that test temperature range, the wet conditioned specimens are brought to the required temperature for 1/2 hour prior to initiation of the tests.

Wet conditioned specimens are tested above 200°F to determine the extent of degradation of properties within 1/2 hour after exposure to the elevated temperature. These tests are conducted in a cabinet that

attained thermal equilibrium in ambient atmospheric conditions. Tests on the successive specimens are initiated between 20 to 25 minutes after insertion into the cabinet at the test temperature. Tests are to be completed within 1/2 hour after introduction of the specimens in the cabinet.

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R5D	Directory in Plastics - Knowledgeable Government Personnel (Revised), by R.J. Valles and John Nardone, Feb 1975 (Price \$20.00)	AD A008 340
37	Polyurethane Foams: Technology, Properties and Applications, by A.H. Landrock, Jan 1969 (Price \$15.50)	AD 688 132
R37A	Ecological Disposal of Plastics with Emphasis on Foam-in-Place Polyurethane Foam, by A.H. Landrock, Aug 1973 (Price \$10.00)	AD 771 342
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39	Subject Index, Bibliography, and Code Description of Technical Conference Papers on Plastics: 15 May 1968-8 May 1969, by J.B. Titus and A.E. Molzon, Dec 1969 (Price \$8.00)	AD 707 246
40	Compatibility of Explosives with Polymers (III). An Addendum to Picatinny Arsenal TR 2595 and PLASTEC Report 33, by N.E. Beach and V.K. Canfield, Jan 1971 (Price \$6.00)	AD 721 004
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R44*	Plastic Materials for Cartridge Cases, by A.M. Shibley, Jan 1973	AD 912 075L
R45	Reverse Osmosis Bibliography: Abstracted and Indexed, by J.B. Titus, June 1973 (Price \$17.00)	AD 769 208
R46*	Nonmetallic Rotating and Obturating Bands: An Annotated Bibliography, by J.B. Titus, Mar 1977	AD B018 466L

NOTES

N6C	Government Specifications and Standards for Plastics Covering Defense Engineering Materials and Applications (Revised, Final), by N.E. Beach, May 1973 (Price \$3.00)	AD 771 008
N9B	Trade Designations of Plastics and Related Materials (Revised), by J.B. Titus, Oct 1974 (Price \$13.00)	AD A001 856
20	Literature Survey on Thermal Degradation, Thermal Oxidation, and Thermal Analysis of High Polymers (III), by D.A. Teetsel and D.W. Levi, Nov 1969 (Price \$10.00)	AD 706 811
21	Literature Search: Injection Molding Processing Parameters, by N.T. Baldanza, July 1969 (Price \$3.00)	AD 703 530
22	Compatibility of Explosives with Polymers: A Guide to the Reactions Reported in Picatinny Arsenal Technical Report 2595, March 1959, by M.C. St. Cyr and N.E. Beach, Oct 1970 (Price \$3.00)	AD 716 624
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